ROCK GLACIERS IN ALASKA[1]

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It is a generally admitted fact among observers of present-day geologic processes in high latitudes, but one upon which too little emphasis has been placed, that processes of weathering and removal of rock waste in sub-arctic regions are different from the controlling processes of degradation in more temperate regions. Among the better-known special agents of erosion active at high altitudes in temperate regions as well as in lower altitudes in sub-arctic regions, is the action of glacial ice. Of the processes not so well understood or appreciated is that of the flow of soils, or "solifluction," described for Bear Island of the North Atlantic Ocean by J. G. Andersson.[2] Mr. Andersson considers " solifluction " to be an important agent in the peneplanation of areas in high latitudes, and the process is without question a most important one in many parts of Alaska. Other processes which, according to Daly,[3] may be effective in producing an accordance of summits in mountainous regions, accordances which are generally referred to as indicating dissected peneplains, are frost action, glaciation, and wind erosion, all of which are relatively more effective above the vegetation line than below it. The accordance of summits, it is suggested, is produced by the selective action of these agents in attacking most vigorously the higher peaks. Even the ordinary processes of stream erosion are different from those of temperate climates, for the streams are frozen for about seven months a year, and during the open months their action upon the detritus is greatly influenced by the permanently frozen character of the soil, and by ground-ice.

The special agents of degradation with which I wish to deal at

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] J. G. Andersson, "Solifluction, a Component of Subaerial Denudation," *Jour. Geol.*, XIV (1906), 91–112.

[3] Reginald A. Daly, "Summit Levels among Alpine Mountains," *Jour. Geol.*, XIII, No. 2 (1905), 105.

present, however, I have called *rock glaciers*. These rock glaciers occur in unusual numbers and attain exceptionally perfect development on the Nizina Special Quadrangle, where I had an opportunity to study them in the summer of 1909 while working on the geology of the region in a U.S. Geological Survey party in charge of Mr. F. H. Moffitt. The center of the area lies at longitude 143° 40′ W., latitude 61° 20′ N. On the sheet there are more than 30 of these rock glaciers and the valleys which they occupy are in every case cirques excavated at the time of the maximum glaciation of these mountains. The valleys are still on the very border line of glacial conditions, and in fact many of them still have small glaciers at their heads. The great Kennicott Glacier, in the main Kennicott Valley, occupies the bottom of the valley into which many of the rock glaciers discharge. Fig. 1 is a topographic map of a portion of the area.

In material the rock glaciers are composed of angular talus, such as goes to make up the ordinary talus slope, the kind of rock being that of the cirque walls above—porphyry, limestone, greenstone, or shale. In most cases the fragmented rock extends all the way to the head of the cirque, with no ice visible and with little or no snow on the surface. In several instances, however, the rock glaciers grade into true glaciers at their upper ends, without perceptible break. There is, therefore, a complete gradation between the two.

They vary greatly in size, but are usually many times longer than wide, occupying, as they do, the bottoms of cirque-like valleys. Some have wide, fan-shaped heads, and narrow down to a tongue below. Others are narrow above, and deploy into spatulate lobes below (Fig. 1, No. 1). Still others are formed by the junction in a valley of rock glaciers from two or more tributary valleys (Fig. 1, No. 5), but the greater number are narrow bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to two and one-half miles long. The surface slopes vary in different cases from 9° to 18° for the whole course of the rock glacier. As topographic features they are well brought out on Mr. Witherspoon's topographic map of the area, a portion of which is shown in Fig. 1. The individual rock fragments are for the most part small, but attain, in exceptional cases, a diameter of several feet. Six inches would perhaps be about the average diameter in those rock glaciers which are com-

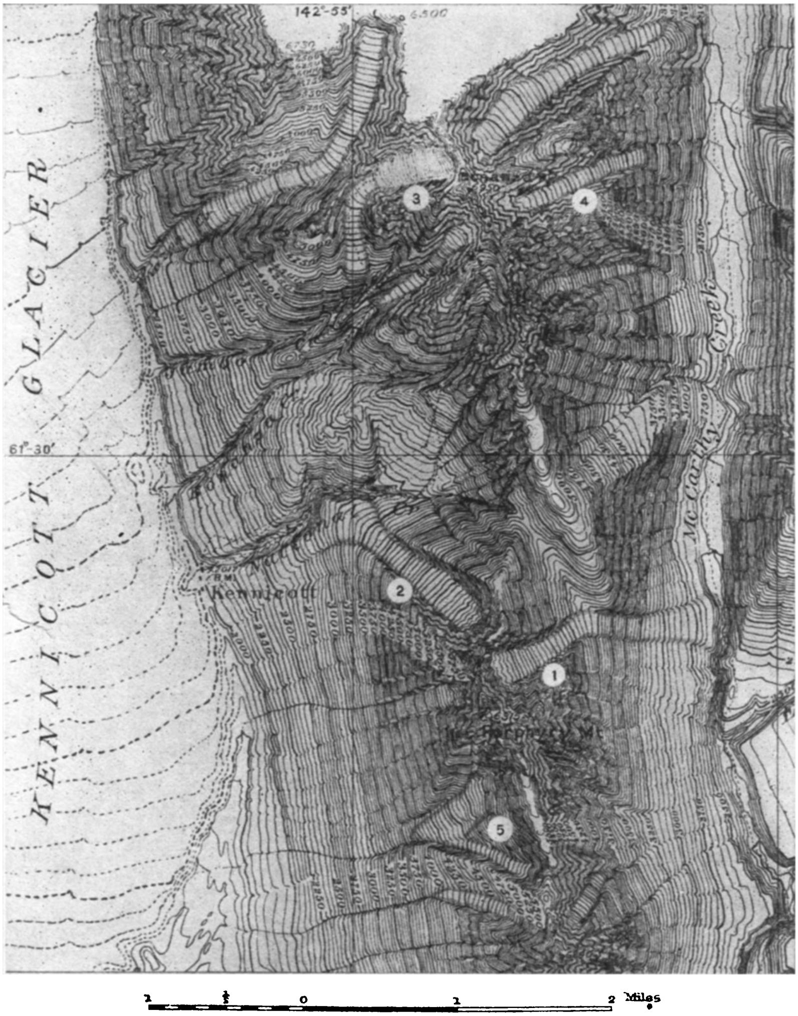

FIG. 1.—Topographic map of about 33 square miles of the Nizina Special Map. Eleven rock glaciers occur within this area. The numbers refer to descriptions in the text. Topography by D. C. Witherspoon.

posed largely of the porphyry, while in the greenstones and limestones the average size of the fragments is larger, and in the shales smaller than this.

The rock glaciers in form and position resemble true glaciers in noticeable ways. They head in cirques and extend from these down the valley, in cross-section being highest above the valley axis and sloping down sharply on the sides. Some were seen to have distinct lateral moraine-like ridges, and all show a more or less well-marked longitudinal ridging.

The surface markings of these rock glaciers are characteristic and striking. In the upper portions there are often many parallel longitudinal ridges, with depressions a few feet deep on either side. The sides below the cirques are usually separated from the rock valley walls by a sharp trough. Toward the lower ends the longitudinal ridges often become less prominent and give place to concentric wrinkles paralleling the lower end of the rock glacier. At the lower edges, the slope often steepens to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as though the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these forms to glaciers led to the suspicion that ice was in some way responsible for their movement. To determine whether or not this was the case a number of the rock glaciers, seven or eight in all, were dug into, and in every instance clear ice was found; not massive ice, however, but interstitial ice, filling the cavities between the angular fragments and forming, with the rock, a breccia with the ice as a matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow diggings which we had time to make. Farther up, toward the cirques in which they headed, the ice could usually be found within a foot or two of the surface, if a depression was dug into. It was often easy to get a drink of water by digging at a point where the sound of running water could be heard, and in these places clear water was found running along shallow courses among the ice-filled talus.

There is a sharp distinction between these rock glaciers and true glaciers, although in some cases it may be difficult to draw the line between the two. For the formation and existence of a true glacier it is necessary to have an annual surplus of snowfall over melt, or, in other words, to have névé fields to supply ice to the glaciers. The greater number of rock glaciers, on the other hand, are found in cirques where all, or practically all, of the winter's snowfall disappears during the summer. In true glaciers, no matter how heavily moraine covered they may be, there is always a tendency to crevass where the ice rounds a bend or passes over an inequality of the bed, and pits and irregularities of the surface are common at the lower ends where the underlying ice melts out and allows the moraines to cave in. In the rock glaciers no certain crevasses or cave-in pits were seen, and these are not to be expected if the rock glaciers are composed, as they seem to be, of talus with ice only in the interstices, for the talus itself is self-supporting without the ice, and the melting of the ice would have little effect on the surface appearance of the flow. This of course is true only of those rock glaciers which show no glacial ice at their upper ends. Of those which head in true glaciers (Fig. 1, No. 3) the upper ends would be profoundly altered if the ice should disappear, but the lower ends would probably present about the same appearance as they do now. The rock glaciers also differ from true glaciers in that, although they may advance spasmodically, or at varying rates, they never retreat, for their form remains intact even if the ice melts out and movement ceases.

The conditions necessary for the formation of one of these rock glaciers are considered to be as follows:

With the wane of the last great epoch of glaciation, the ice in many small valleys which contained glaciers was retreating, and as its area contracted in the cirques, the head walls and sides, steepened by glacial undercutting and by *Bergschrund* sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In the more favorably situated of these cirques the rock waste streamed down the valley sides and heads upon the glacier below and was gradually carried down by the ice and ultimately concentrated at its lower edge. Here, in the usual order of events, it would have been piled up as terminal moraine, but differ-

ing in character from the common forms of terminal moraine material in its angular, talus-like appearance and the absence of finer muds and rock flour which form such a large part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little, and were almost overwhelmed by the débris supplied them from above. Into the detritus at the lower edge of the glacier the waters from the melting ice and snow and from rains sank and froze, and gradually filled the interstices with ice up to a point below the surface where melting equaled the freezing. In these ice-cemented masses an incipient glacial movement was started by the well-known process of melting and refreezing of the waters, with their consequent expansion. As the climate became still milder, in many of the cirques the winter's snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floor became filled with interstitial ice, and the movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has disappeared from many of these rock glaciers. It is certain that much snow is still carried down onto the surface of the rock glaciers in slides of ice and rock, and considerable quantities of it may be covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

The above succession of events seems to be well established in this region, for there are now all stages varying from apparently active glaciers with short rock glaciers below, to rock glaciers in which no glacier ice is seen, in valleys where all snows disappear during the summer, yet in these the slow movement seems still to be in operation, the rate of movement in each rock glacier controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are, therefore, the true successors of real glaciers.

The particularly perfect development of these features in the area of the Nizina Special Map is due to the rugged character of the mountains, with cirques having steep heads and sides; to the exceptionally favorable conditions for rapid rock weathering and talus accumulation; and to climatic conditions peculiar to areas on the border line of glacial activity.

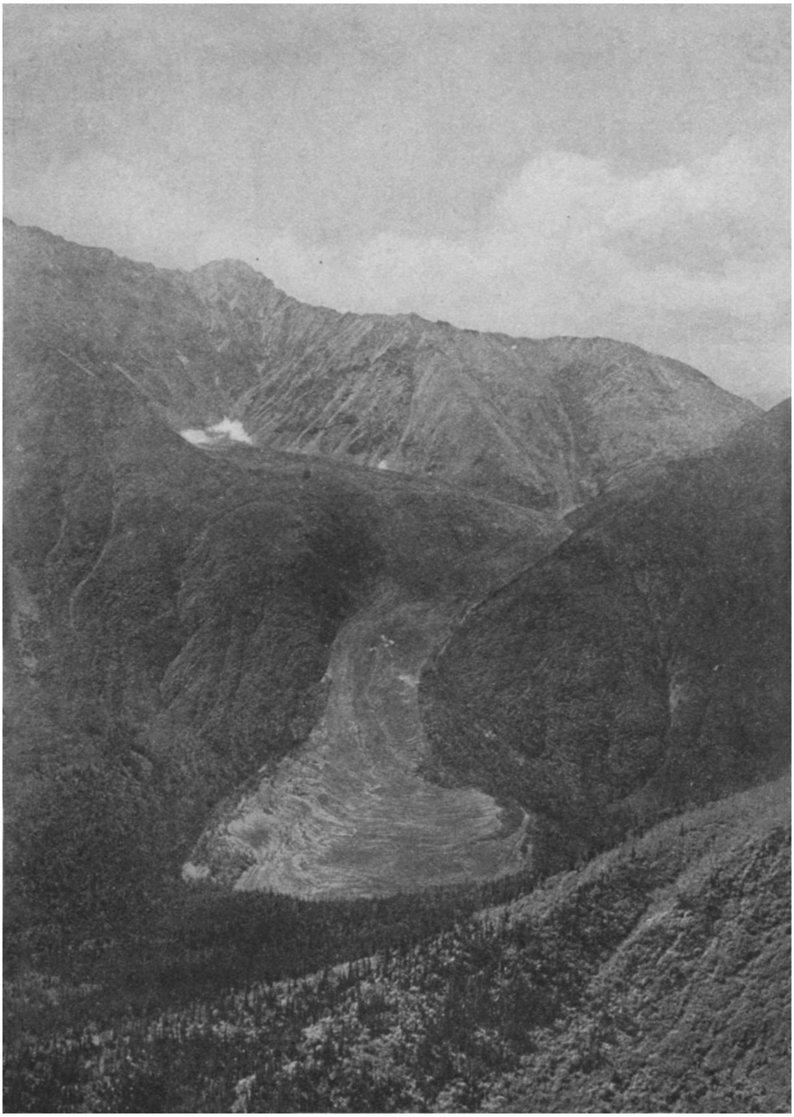

FIG. 2.—Rock glacier on McCarthy Creek (Fig. 1, No. 1). Especial attention is called to the absence of perennial snows at its head; to the longitudinal direction of the surface linings in the upper portion, and to their concentric arrangement in the broad lower portion. Photo by F. H. Moffitt.

The rock glacier which was studied in most detail lies on the west side of McCarthy Creek, east of Kennicott (Fig. 1, No. 1). Although neither so long nor so large in area as others within the limits of the Nizina Special Map, it presents in a typical way many of the notable characteristics of all of the flows (Fig. 2). This rock glacier heads in a glacial cirque in a mountain composed largely of porphyry but

FIG. 3.—The upper portion of a rock glacier (Fig. 1, No. 2), showing the character of the longitudinal ridges, and their relations to the talus slopes in which they head.

having many inclosed masses of black Jurassic shale, the mountains at the cirque head reaching a maximum height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet. Above this talus slopes extend upward for about 200 feet, the remainder of the cirque walls being bare, ragged cliffs. The porphyry is much fractured and the formation of talus unusually rapid. The valley head lies below the elevation necessary for the maintenance of true glaciers, and the winter's snows disappear completely during the summer. On July 4, the time visited, but little snow remained.

The rock glacier heads in the talus cones which have formed at the base of the steep rock cliffs. These cones have nowhere grown to large size, the materials evidently having moved on down valley as parts of a rock glacier as fast as they were supplied from above. From the base of the more vigorous talus cones smooth, ridgelike lines extend on down the rock glacier, seeming to show that the forward

FIG. 4.—Profile of rock glacier on McCarthy Creek (Fig. 1, No. 1). The surface scope of the rock glacier conforms in a noticeable way with the glacial U-shape of the McCarthy Creek valley.

movement has been uniform and continuous. This is especially well shown for the flow on the opposite side ot the ridge (Fig. 1, No. 2), in Fig. 3. The longitudinal ridges mark the surface for the upper three-fourths of the total length of the flow. The cirque basin is a hanging valley extending down to an elevation of about 4,000 feet, below which it joins the broad V-shaped valley of the McCarthy Creek. As it passes over the lip of this hanging cirque the rock glacier cascades steeply down the valley side (Fig. 4), and upon reaching the gentler slope below, being no longer confined by restricting valley

walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings disappear and give place to a set of concentric ridges or wrinkles, shown in Fig. 2, and in greater detail in Fig. 5. The origin of these wrinkles is not clear, but they strongly suggest rings of growth, and may represent the amount of annual movement of the rock glacier.

FIG. 5.—Concentric ridges on lower portion of rock glacier in McCarthy Creek valley (Fig. 1, No. 1).

At its foot the flow has pushed across the valley bottom almost to the base of the east valley wall. McCarthy Creek has been forced to the eastward, and occupies a narrow channel between the foot of the rock glacier and the rock valley wall (Fig. 6). The foot of the rock glacier is being cut into by the stream, and in places shows a face 75 to 100 feet high in which the slope is about 35 degrees, or the angle of rest for this material. The stream has been able only to keep its channel open along the foot of the rock glacier, and it seems probable that the flow is moving forward as fast as the stream can cut it back.

I have been able to find in the literature scant reference to features of this kind. In the Falkland Islands there are so-called "stone rivers," described by Thomson,[1] Andersson,[2] and others, which seem to correspond closely to those in the area here described, but which occur on much lower slopes. Andersson, in an article on "Solifluction," or soil flow, thinks that these Falkland "stone rivers," which now

FIG. 6.—Lower end of rock glacier on McCarthy Creek (Fig. 1, No. 1). The material at the edge lies at an angle of 35°. The stream has been able to keep open only a narrow channel at the base of the rock glacier.

are composed of angular blocks, were formerly filled with fine mud and that the blocks of rock, buoyed up by the mud, slowly flowed down the valleys. He conceives that the fine material has since been removed by running water. There is now no movement of these "stone rivers."

The rock glaciers do not fall under the term "solifluction," as used by Andersson, for he describes a movement of rock débris com-

[1] Thomson, *The Atlantic*, 245.

[2] J. G. Andersson, *op. cit.*

posed of angular fragments mingled with a matrix of mud, which moves as a viscous fluid. The material of the rock glaciers is for the most part coarse and angular, and instead of a semi-liquid filling of mud, the interstitial openings are filled with solid ice, except in the surface portions, where there is no filling at all.

There is also an opportunity for interesting comparisons with the rock slides of the San Juan Mountains of Colorado, so well described by Cross and Howe[1] in the Silverton Folio and by Howe[2] in a recent publication. At first glance there seems to be a great similarity between the rock streams of the Colorado Mountains and the rock glaciers of the area under discussion. Both are composed of angular talus from high mountains, and show some striking similarities in appearance and in surface configuration. I am convinced, however, that the rock glaciers of the Nizina region are not formed in the way in which Mr. Howe[3] explains his rock streams, by a flow down the slopes "with a sudden violent rush that ended as quickly as it started." No opportunity has so far been had to make a series of observations extending over a considerable period of time to prove conclusively that these rock glaciers are in motion, or to determine the rate of movement. There are a number of facts, however, which seem to lead inevitably to this conclusion.

In the Silverton Folio, published in 1903, Cross and Howe state: "The larger rock streams, however, must owe their origin to glaciers; no other agencies could transport such vast quantities of rock waste so far from their sources." Later, Howe has published his opinion that the rock streams of the San Juan Mountains are really landslides, which occurred in a sudden violent rush of material. In this opinion Cross now agrees with him.

In his description of the great Elm landslide, Heim[4] has pointed out that sudden landslides may have a form remarkably similar to that which is developed by slow movement, and it is well to keep this

[1] Whitman Cross and Ernest Howe, *U.S. Geol. Sur. Folio*, No. 120, Silverton.

[2] Ernest Howe, "Landslides in the San Juan Mts., Colo.," professional paper, *U.S. Geol. Sur.*, 67, 1909.

[3] *Ibid.*, p. 54.

[4] Albert Heim, "Der Bergsturz von Elm," *Zeitschr. Deutsch. Geol. Gesell.*, 1882, 98.

fact in mind. McConnell and Brock,[1] on the other hand, in their report on the Frank landslide, fail to report any systematic ridgings like those at Elm, or in the rock streams of the San Juan Mountains.[2]

Perhaps the most indicative facts which lead us to conclude that the rock glaciers of the Nizina region are now in motion, moving in some such way as a glacier, are:

FIG. 7.—The upper end of a rock glacier, showing the cirque-like character of the valley head, and the origin of the longitudinal ridges in the talus slopes of the head walls.

1. The remarkable resemblance in position and form to present live glaciers in the immediate vicinity.

2. The direct connection and perfect gradation between present glaciers above and long rock glaciers below.

3. The presence of interstitial ice at no great depth below the surface in all of the rock glaciers which were dug into.

[1] R. G. McConnell and R. W. Brock, "Report on the Great Landslide at Frank, Alta., 1903," *Ann. Rept.*, Dept. Interior, Canada, 1903, pt. 8.

[2] Ernest Howe, *op. cit.*

4. The longitudinal ridges seen at the upper ends of many of the rock glaciers can often be followed directly to an active talus slope (Figs. 3 and 7).

5. Nowhere have the talus slopes at the heads of the cirques been able to form any considerable accumulations on the surface of the rock glaciers. This seems to be very strong evidence that the talus

FIG. 8.—A small rock glacier north of Sourdough Peak. The characteristic steep lower face of these features is well shown.

has moved on down the valley as fast as it has been supplied (Figs. 3 and 7).

6. In all of the best examples of rock glaciers there is a steep slope at the lower end where the gently sloping surface of the upper portion breaks down at the edge at an angle as steep as the talus will lie. Over this steep face the rock fragments are fresh, while the talus on the surface above this slope is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion of the lower end from reducing it to a low, graded slope (Fig. 8).

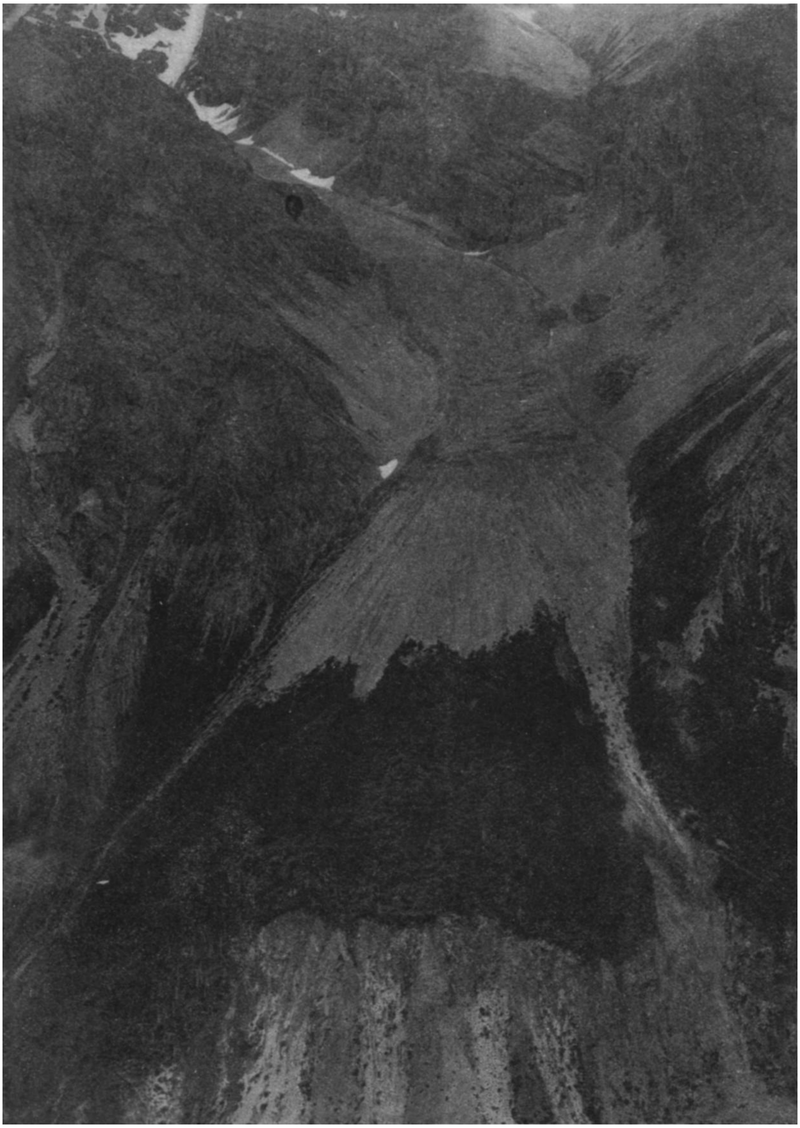

FIG. 9.—Rock glacier in McCarthy Creek valley (Fig. 1, No. 4). It terminates below at the mouth of the hanging valley in which it lies, this being the point at which the interstitial ice fails to make possible a slow glacier-like movement. The material from the end of the rock glacier has streamed down to form a well-developed talus cone. Photo by F. H. Moffitt.

7. In the fine example on the west side of McCarthy Creek (Fig. 1, No. 1), the creek, a swift stream of large volume, is now actively cutting into the lower end of the rock glacier, which has been in existence long enough for large spruce trees to grow upon its surface. Nevertheless, the creek has so far been unable to do more than keep a narrow channel open along the foot of the rock glacier (Fig. 6).

FIG. 10.—Rock glacier at head of White Creek. The detritus from the two sides of the rocky island flows together to form a single stream below it.

Yet there is no evidence that the rock glacier ever extended the 75 feet farther east which would have carried it to the rock bluff on the east side of the valley. It seems unusual that this mass of material, if it came down with a rush, should have failed by just the width of the creek to cross the valley, and also that the stream, which is now actively cutting into the face of this rock glacier, has been unable to do more than keep its channel open. It appears as much more probable that the slowly advancing edge of the rock glacier has been removed by the stream as rapidly as it has moved forward.

8. There is no evidence that important landslides have taken place

in this region, if these features are not landslides. None were seen below the miles of prominent, steep cliffs of the area, though ordinary talus cones are abundant.

9. One rock glacier, in a western tributary of McCarthy Creek (Fig. 1, No. 4, and Fig. 9), shows all the characteristics of a typical rock glacier at its upper end, but at the mouth of the hanging valley on which it lies, it streams down to McCarthy Creek as a very perfect talus cone. If it had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the talus cone indicates that the material of which it is composed was supplied slowly, thus enabling the cone to build up symmetrically. The talus cone is still being supplied with material by the rock glacier, as may be seen in the figure from the way in which the talus from above is invading the patch of alder bushes on the side of the cone.

10. Wherever two rock glaciers in adjacent cirques join below to form a single flow, the point of junction shows that the two branches have flowed together synchronously without any evidence that the flow from one branch has come down and overridden that from the other (Fig. 10).